Dose Estimates for the Marine Food Chain

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Introduction

This analysis is designed to estimate the dose via the marine pathway. The dose assessment is based upon the marine diet discussed in the chapter on dietary and living patterns (Table 139).

Data Bank

The data bank contains analytical results from slightly over 800 fish and approximately 50 edible invertebrates collected during the 1972 Enewetak survey (for a detailed description see the marine survey chapter). Data from the analysis of the radionuclide concentration in fish muscle have been summarized in several different ways to help in the interpretation and the assessment of the values to be used in the dose code. Figure 118 indicates the various forms of the summarized data.

Table 153* lists the average radionuclide concentration — with concentrations for a nondetected nuclide set equal to the detection limit in column 4 and concentrations for nondetected nuclides set equal to zero in column 7 — for each species for samples collected at each island and in the open lagoon. Table 154 (on microfiche) presents the summary of the average radionuclide concentration for each species for the entire Atoll, regardless of location. The nuclides are identified by the sequence of numbers in the nuclide column. The first two digits give the atomic number and the last three digits give the isotope mass number; therefore 55137 is ^{137}Cs. The tables also include the tissue, the number of samples in the average, the range of individual values, and, because of the skewed distribution observed in this survey and observed for trace elements and radionuclides in other populations [1-3], the lognormal median for comparison with the average value.

The reef fishes are the most plentiful around the Atoll and are the easiest to catch. Therefore they make up a considerable portion of the fresh fish intake in the diet. The most plentiful reef fishes, and also three of the preferred fish in the diet, are surgeonfish, goatfish,

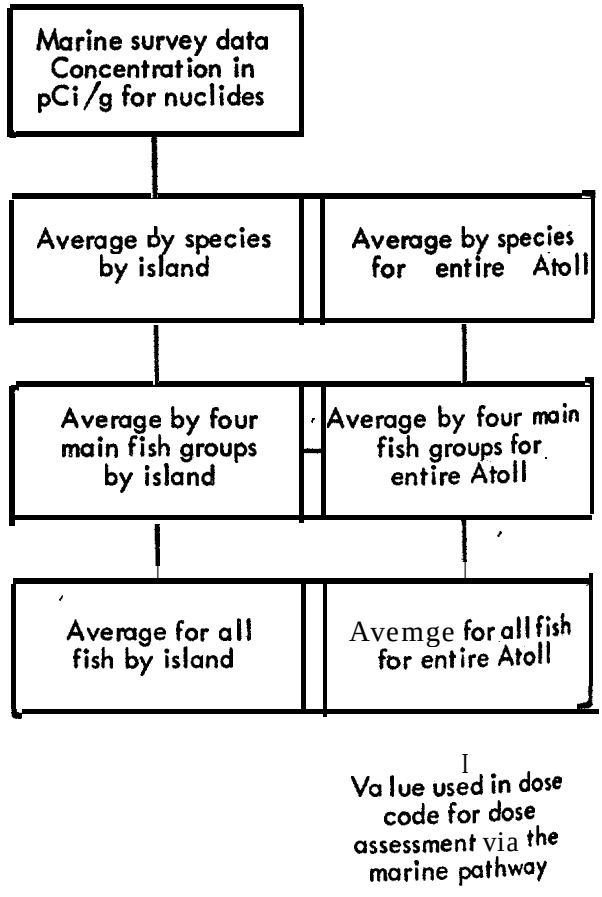
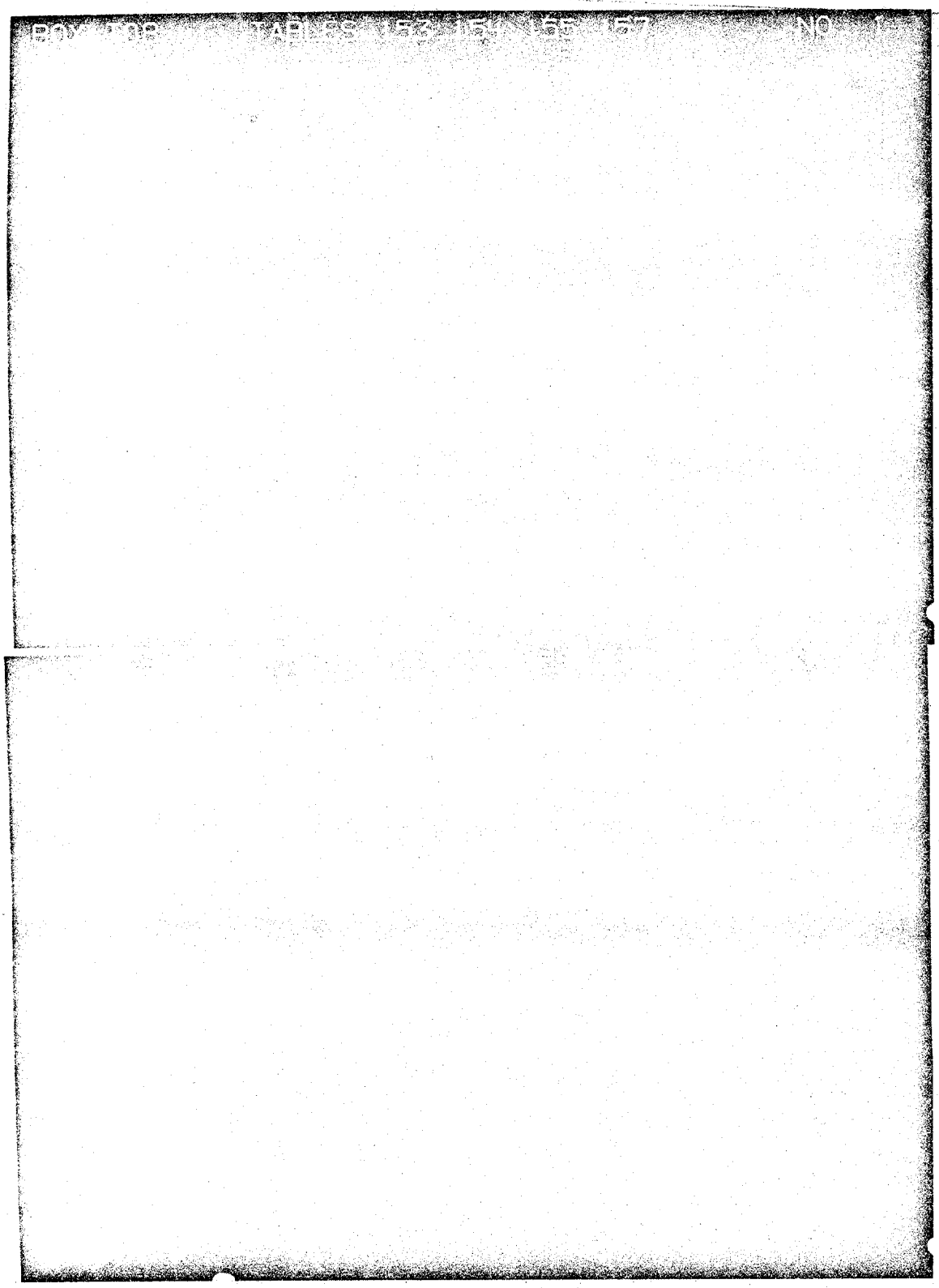


Fig. 118. Summaries of marine concentration data.

*Because of the sheer bulk of the data, Tables 153- 155 and 157 have been reproduced on microfiche film and may be found in the envelope mounted on p. 527.

Tables 153, 154, 155, and 157.
Radionuclide concentration in fish muscle,



and mullet. Other reef fish are eaten but are not as plentiful. In addition, the larger pelagic, predator fish are eaten, but they are harder to catch and therefore supply much less of the fish diet than the reef fishes,. Tridacna clams also constitute a small portion, of the diet. They are considered a delicacy, are not available in large quantity, and are usually eaten raw at the time of catch. Lingusta (lobster) are also considered a delicacy but contribute a very small portion of the marine diet.

Therefore the next summary presents the average radionuclide concentration of four main fish groups — surgeonfish, goatfish, mullet and "other"-- where "other" includes all species other than the three mentioned, including the tridacna clams and lingusta., The summary is shown in Table 155 (on microfiche) and is island specific.

Table 156, incorporated in the text, lists the average concentration of the radionuclides in the four fish groups for the entire Atoll. The number of samples in the average -concentration, the standard deviation, and the high and low of the range are all given. The plot of the concentration of ^{137}Cs, ^{60}Co, and ^{90}Sr, the three main isotopes found in fish muscle, for the four fish groups is shown in Fig. 119. The standard deviations for each of the four fish groups were a factor of 2 to 3 times greater than the difference between the range of the mean values, There was therefore no statistically significant difference in the mean values of the four groups; however, the Kruskal-Wallis nonparametric test did indicate a difference in the total distribwtion for ^{60}Co and ^{90}Sr.

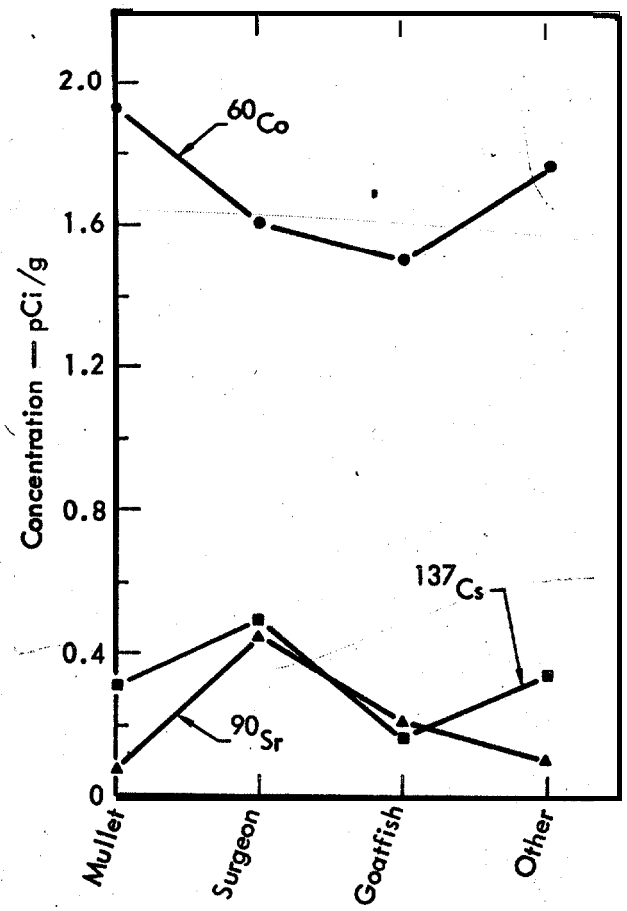


Fig. 119. Average concentration of ^{137}Cs, ^{60}Co, and ^{90}Sr for the four fish groups for the entire Atoll.

Because there were no statistically significant differences between mean values for the four major fish categories, the radionuclide concentration was averaged by island for all fish. These results are given in Table 157 (on microfiche). Figures 120-122 show a plot of the ^{137}Cs, ^{60}Co, and ^{90}Sr average nuclide concentration in all fish as a function of island location.

There appears to be a higher concentration of the three radionuclides in fish from ALICE through IRENE than from islands JANET through LEROY. Although individual-samples from islands JANET through LEROY had concentrations in the

Table 156a. Summary of radionuclide concentrations for the entire Atoll for mullet.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
40 K	MUSCLE	26	8.141E+00	3.697E+00	1.686E+01	2.982E+00	8.141E+00	7.402E+00
55 FE	MUSCLE	26	8.022E+00	2.114E+01	1.104E+02	5.586E-01	8.022E+00	3.280E+00
60 CO	MUSCLE	27	1.930E+00	4.132E+00	2.189E+01	1.495E-01	1.904E+00	8.237E-01
90 SR	MUSCLE	25	8.181E-02	8.926E-02	3.041E-01	3.459E-03	5.811E-02	4.216E-02
106 RU	MUSCLE	21	7.581E-01	3.077E-01	1.379E+00	3.618E-01	0.	7.003E-01
102 RH	MUSCLE	27	8.399E-02	7.316E-02	3.729E-01	2.536E-02	0.	6.557E-02
125 SB	MUSCLE	27	2.620E-01	3.782E-01	2.096E+00	7.734E-02	7.763E-02	1.871E-01
137 CS	MUSCLE	27	3.248E-01	8.185E-01	4.344E+00	2.636E-02	2.754E-01	1.400E-01
133 BA	MUSCLE	19	1.167E-01	1.003E-01	4.178E-01	2.753E-02	0.	8.557E-02
144 CE	MUSCLE	1	2.877E-01	0.	2.877E-01	2.877E-01	0.	2.877E-01
152 EU	MUSCLE	27	7.659E-02	3.908E-02	1.323E-01	3.060E-02	0.	6.716E-02
155 EU	MUSCLE	27	1.058E-01	4.897E-02	1.690E-01	3.696E-02	1.243E-02	9.333E-02
207 BI	MUSCLE	27	6.412E-02	3.964E-02	2.077E-01	2.105E-02	1.678E-02	5.517E-02
235 U	MUSCLE	26	6.505E-02	3.817E-02	1.843E-01	2.350E-02	0.	5.570E-02
239,240 PU	MUSCLE	25	9.840E-01	4.603E+00	2.306E+01	4.820E-04	9.813E-01	1.446E-02
238 PU	MUSCLE	13	1.055E-02	9.426E-03	3.036E-02	1.811E-03	3.186E-03	7.706E-03
241 AM	MUSCLE	27	9.824E-02	4.805E-02	1.722E-01	2.613E-02	0.	8.429E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156b. Summary of radionuclide concentrations for the entire Atoll for surgeon.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
3 H	MUSCLE	4	3.298E-01	1.166E-01	4.698E-01	1.845E-01	3.298E-01	3.128E-01
40 K	MUSCLE	25	1.004E+01	2.552E+00	1.598E+01	7.194E+00	1.004E+01	9.758E+00
55 FE	MUSCLE	27	9.892E+00	1.364E+01	6.757E+01	2.703E-01	9.750E+00	4.718E+00
60 CO	MUSCLE	28	1.815E+00	5.789E+00	3.106E+01	6.108E-02	1.765E+00	4.647E-01
90 SR	MUSCLE	27	2.098E-01	2.801E-01	1.275E+00	6.441E-03	2.029E-01	9.282E-02
106 RU	MUSCLE	27	7.073E-01	4.951E-01	2.104E+00	3.017E-01	0.	5.938E-01
102 RH	MUSCLE	28	6.618E-02	7.081E-02	3.719E-01	1.805E-02	0.	4.894E-02
125 SB	MUSCLE	28	1.816E-01	1.243E-01	4.806E-01	7.757E-02	0.	1.515E-01
137 CS	MUSCLE	28	5.387E-01	1.271E+00	6.779E+00	4.363E-02	5.056E-01	2.222E-01
133 BA	MUSCLE	20	7.708E-02	8.988E-02	4.005E-01	2.445E-02	0.	5.292E-02
152 EU	MUSCLE	28	7.342E-02	4.802E-02	1.924E-01	3.200E-02	0.	6.184E-02
155 EU	MUSCLE	28	8.593E-02	5.551E-02	2.044E-01	3.097E-02	0.	7.105E-02
207 BI	MUSCLE	28	1.158E-01	1.529E-01	7.739E-01	1.965E-02	7.367E-02	6.825E-02
235 U	MUSCLE	28	5.434E-02	3.857E-02	1.821E-01	2.271E-02	0.	4.509E-02
239,240 PU	MUSCLE	28	7.724E-02	1.689E-01	8.874E-01	4.279E-03	7.683E-02	2.804E-02
238 PU	MUSCLE	8	8.100E-03	6.707E-03	2.207E-02	1.802E-03	4.561E-03	5.862E-03
241 AM	MUSCLE	28	8.431E-02	5.731E-02	1.920E-01	2.232E-02	0.	6.583E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

238 PU	MUSCLE	8	8.100E-03	6.707E-03	2.207E-02	1.802E-03	4.561E-03	5.862E-03
241 AM	MUSCLE	28	8.431E-02	5.731E-02	1.920E-01	2.232E-02	0.	6.583E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156c. Summary of radionuclide concentrations for the entire Atoll for goatfish.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
3 H	MUSCLE	3	4.108E-01	6.860E-02	4.622E-01	3.329E-01	4.108E-01	4.067E-01
40 K	MUSCLE	19	9.662E+00	2.464E+00	1.637E+01	5.946E+00	9.662E+00	9.374E+00
55 FE	MUSCLE	20	3.012E+01	8.358E+01	3.833E+02	1.676E+00	3.012E+01	1.002E+01
60 CO	MUSCLE	21	1.506E+00	3.087E+00	1.477E+01	1.608E-01	1.483E+00	7.914E-01
90 SR	MUSCLE	21	2.152E-01	3.527E-01	1.541E+00	1.212E-02	2.152E-01	1.036E-01
106 RU	MUSCLE	10	7.548E-01	4.684E-01	1.943E+00	3.768E-01	0.	6.633E-01
102 RH	MUSCLE	21	8.293E-02	4.513E-02	1.714E-01	2.643E-02	0.	7.224E-02
125 SB	MUSCLE	21	2.978E-01	3.943E-01	1.986E+00	9.743E-02	1.064E-01	2.242E-01
137 CS	MUSCLE	21	1.718E-01	1.963E-01	9.878E-01	4.201E-02	1.018E-01	1.324E-01
133 BA	MUSCLE	19	1.675E-01	1.052E-01	4.118E-01	2.785E-02	2.168E-02	1.275E-01
144 CE	MUSCLE	1	2.739E-01	0.	2.739E-01	2.739E-01	0.	2.739E-01
152 EU	MUSCLE	21	5.915E-02	4.338E-02	1.903E-01	2.779E-02	0.	4.942E-02
155 EU	MUSCLE	21	1.208E-01	8.445E-02	4.122E-01	3.777E-02	3.332E-02	1.018E-01
207 BI	MUSCLE	21	7.464E-01	5.320E-01	1.633E+00	1.214E-01	7.379E-01	5.555E-01
235 U	MUSCLE	20	9.357E-02	4.347E-02	1.508E-01	2.482E-02	0.	8.070E-02
239,240 PU	MUSCLE	21	1.299E-02	1.513E-02	5.315E-02	1.608E-03	1.231E-02	7.782E-03
238 PU	MUSCLE	12	1.066E-02	7.512E-03	2.432E-02	3.153E-03	5.405E-03	8.290E-03
241 AM	MUSCLE	21	1.111E-01	4.604E-02	2.053E-01	2.774E-02	0.	9.907E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

Table 156d. Summary of radionuclide concentrations for the entire Atoll for other fish.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
3 H	MUSCLE	2	5.040E-01	3.040E-01	7.189E-01	2.890E-01	5.040E-01	4.558E-01
40 K	MUSCLE	46	1.593E+01	5.369E+00	2.697E+01	3.355E+00	1.593E+01	1.481E+01
55 FE	MUSCLE	50	1.717E+01	3.209E+01	1.968E+02	1.577E-01	1.704E+01	5.012E+00
60 CO	MUSCLE	52	2.347E+00	6.448E+00	3.827E+01	4.063E-02	2.282E+00	5.167E-01
90 SR	MUSCLE	52	1.403E-01	2.207E-01	8.514E-01	1.051E-03	6.268E-02	5.129E-02
106 RU	MUSCLE	30	9.528E-01	4.861E-01	2.237E+00	3.236E-01	0.	8.466E-01
102 RH	MUSCLE	52	1.099E-01	6.257E-02	2.954E-01	2.481E-02	0.	9.180E-02
113 CD	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
125 SB	MUSCLE	52	2.486E-01	1.424E-01	1.025E+00	7.788E-02	1.295E-02	2.212E-01
137 CS	MUSCLE	52	4.311E-01	5.679E-01	3.089E+00	2.689E-02	4.035E-01	2.539E-01
133 BA	MUSCLE	46	1.726E-01	1.342E-01	7.631E-01	2.632E-02	2.718E-02	1.284E-01
144 CE	MUSCLE	2	2.837E-01	1.949E-02	2.975E-01	2.699E-01	0.	2.834E-01
152 EU	MUSCLE	52	8.945E-02	7.507E-02	3.415E-01	2.933E-02	0.	6.866E-02
155 EU	MUSCLE	52	1.226E-01	9.119E-02	5.212E-01	3.570E-02	1.482E-02	1.019E-01
207 BI	MUSCLE	52	5.532E+00	3.499E+01	2.527E+02	2.074E-02	5.493E+00	1.776E-01
235 U	MUSCLE	48	9.569E-02	5.005E-02	2.547E-01	2.382E-02	0.	8.192E-02
239,240 PU	MUSCLE	49	7.000E-02	2.383E-01	1.212E+00	7.883E-04	6.368E-02	9.092E-03
238 PU	MUSCLE	31	1.805E-02	2.984E-02	1.140E-01	2.063E-03	6.089E-03	7.982E-03
241 AM	MUSCLE	52	1.404E-01	1.130E-01	8.023E-01	2.700E-02	6.820E-03	1.148E-01

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

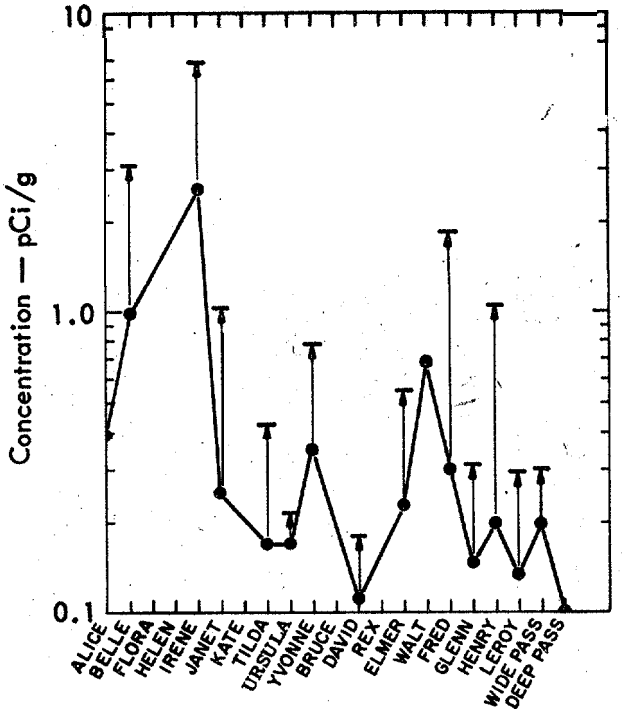


Fig. 120. ^{137}Cs concentrations *in* marine samples as a function of location in the Atoll. The bar above each vertical arrow indicates the maximum value for a sample included in the average. No bar or arrow indicates a single sample.

same range as individual samples for islands ALICE through IRENE, there was definitely a significant difference for the ^{137}Cs and ^{60}Co ($p = 0.001$ Mann-Whitney U Test) concentrations for fish from ALICE through IRENE, versus those from JANET through LEROY. There was no significant difference between these island groups for fish muscle samples for ^{90}Sr. If fish samples for eviscerated whole fish (which includes the bones) are included, then ^{90}Sr concentrations do test differently for these island groups.

However, the people living on Engebi (JANET) will fish both east and west of the island; that is, they will fish off the islands ALICE through IRENE, but will also fish off the islands KATE through WILMA, In essence, the people living on Engebi will fish the northern half of the Atoll. Therefore, in their fish diet, they will integrate the concentrations of the fish from the northern half of the Atoll, i. e. , ALICE through WILMA. Again using the Mann-Whitney U Test, concentration values for the three isotopes for all fish from islands ALICE through WILMA, i. e., the northern half of the Atoll, were tested against the concentration values for all fish from islands ALVIN through LEROY., i. e. , the southern

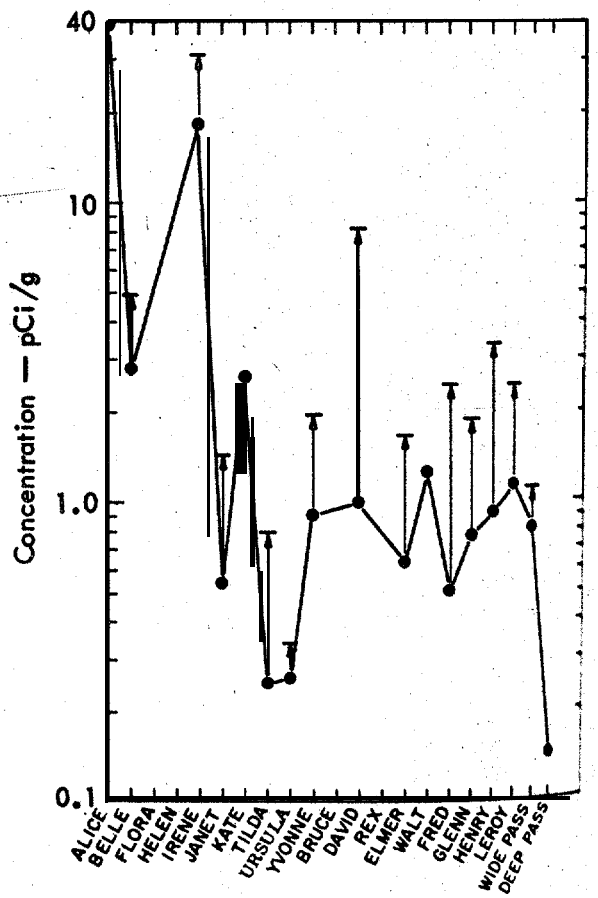


Fig. 121. ^{60}Co concentrations in marine samples as a function of location in the Atoll, The bar above each vertical arrow indicates the maximum value for a sample included, in the average. No bar or arrow indicates a single sample.

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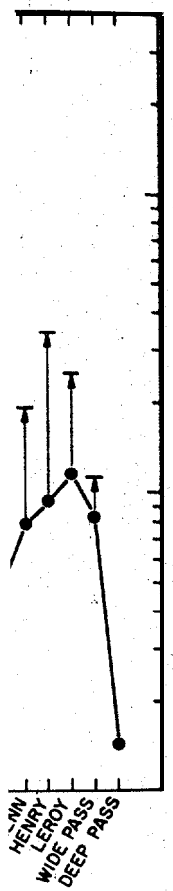

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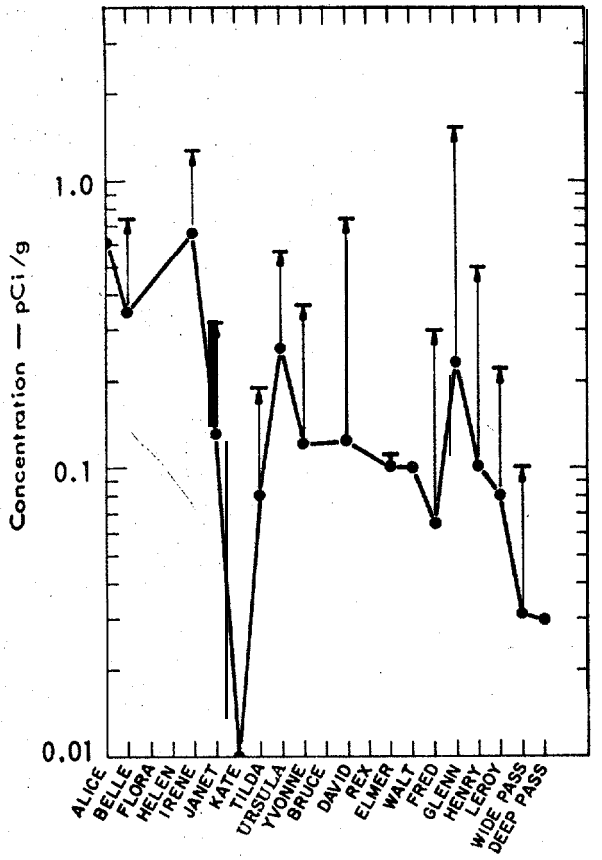


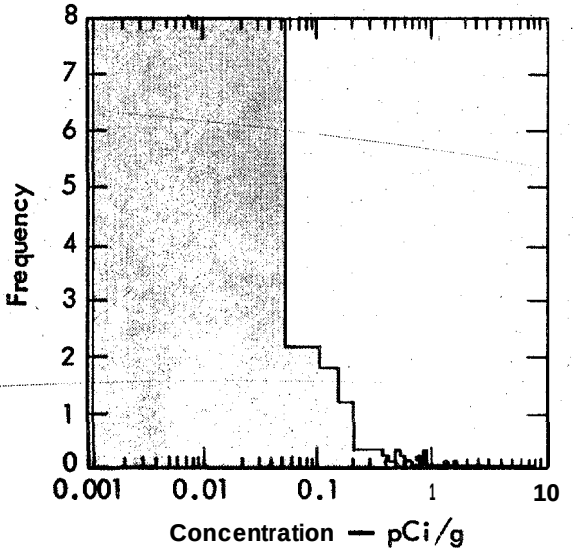
Fig. 122. ^{90}Sr concentrations in marine samples as a function of location in the Atoll. The bar above each vertical arrow indicates the maximum value fdr a sample included in the average. No bar or arrow indicates a single sample.

half of the Atoll. The results for fish muscle show no difference between the two halves of the Atoll for ^{90}Sr (p = 0. 7), ^{137}Cs (p = 0. 1), and ^{60}Co (p = 0.4). ^{137}Cs and ^{90}Sr tested as significantly different (p = 0. 001) for eviscerated whole fish which included bone; however, the average concentration in this case for the two halves of the Atoll differs by only a factor of 3 for ^{137}Cs and a factor of 2 for ^{90}Sr, and the average for the entire Atoll is less by only a factor of 2 for ^{137}Cs and only 30% for ^{90}Sr than the average of the northern half *alone.*

As a result of the above analysis and the fact that the Enewetak people eat only the muscle portion of the fish, the average concentration (with concentrations for nondetected radionuclides set equal to the detection limit) for fish from the entire Atoll was used in the dose code.

Table 158 lists the average concentration, the number of samples in the average, the standard deviation, and the high and low of the range for each radionuclide for all fish.

The concentration distributions for ^{90}Sr, ^{137}Cs, and ^{60}Co are quite skewed (Figs. 123 - 125,) and are consistent with other, published data on radionuclide and trace-element distribution in fish, animals, and humans (1, 2, 3). The lognormal median is therefore included in the Table 158 for comparison with the average value. In general, the lognormal median is 3 to 4 times less than the average. However, to estimate the average population dose for the marine pathway



Fig, 123. Histogram plot' of the ^{90}Sr concentration in all fish from the entire Atoll.

Table 158. Average concentration, number of samples in the average, standard deviation, and high and low of the range for all fish in the entire Enewetak Atoll.

NUCLIDE	TISSUE	NO. OF SAMPLES	AVERAGE PCI/GRAM*	STANDARD DEVIATION	RANGE PCI/GRAM HIGH	LOW	AVERAGE PCI/GRAM**	LOGNORMAL MEDIAN PCI/GRAM
01003	MUSCLE	9	3.955E-01	1.517E-01	7.189E-01	1.845E-01	3.955E-01	3.712E-01
19040	MUSCLE	116	1.189E+01	5.277E+00	2.697E+01	2.982E+00	1.189E+01	1.075E+01
26055	MUSCLE	123	1.574E+01	4.108E+01	3.833E+02	1.577E-01	1.566E+01	5.063E+00
27060	MUSCLE	128	2.005E+00	5.377E+00	3.827E+01	4.063E-02	1.958E+00	5.974E-01
38090	MUSCLE	125	1.562E-01	2.460E-01	1.541E+00	1.051E-03	1.177E-01	6.308E-02
44106	MUSCLE	88	8.085E-01	4.558E-01	2.237E+00	3.017E-01	0.	7.058E-01
45102	MUSCLE	128	9.044E-02	6.601E-02	3.729E-01	1.805E-02	0.	7.165E-02
48113	MUSCLE	1	2.635E-01	0.	2.635E-01	2.635E-01	2.635E-01	2.635E-01
51125	MUSCLE	128	2.449E-01	2.581E-01	2.096E+00	7.734E-02	3.910E-02	1.970E-01
55137	MUSCLE	128	3.897E-01	7.940E-01	6.779E+00	2.636E-02	3.493E-01	1.955E-01
56133	MUSCLE	104	1.431E-01	1.205E-01	7.631E-01	2.445E-02	1.598E-02	1.004E-01
58144	MUSCLE	4	2.822E-01	1.269E-02	2.975E-01	2.699E-01	0.	2.820E-01
63152	MUSCLE	128	7.826E-02	5.899E-02	3.415E-01	2.779E-02	0.	6.329E-02
63155	MUSCLE	128	1.107E-01	7.631E-02	5.212E-01	3.097E-02	1.411E-02	9.242E-02
83207	MUSCLE	128	2.409E+00	2.233E+01	2.527E+02	1.965E-02	2.372E+00	1.358E-01
92235	MUSCLE	122	7.932E-02	4.723E-02	2.547E-01	2.271E-02	0.	6.563E-02
94000	MUSCLE	123	2.477E-01	2.083E+00	2.306E+01	4.820E-04	2.444E-01	1.257E-02
94238	MUSCLE	64	1.390E-02	2.175E-02	1.140E-01	1.802E-03	5.241E-03	7.679E-03
95241	MUSCLE	128	1.144E-01	8.462E-02	8.023E-01	2.232E-02	2.771E-03	9.298E-02

*AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO DETECTION LIMIT) PCI/GRAM
**AVERAGE (IF NON-DETECTED, CONCENTRATION SET EQUAL TO ZERO) PCI/GRAM

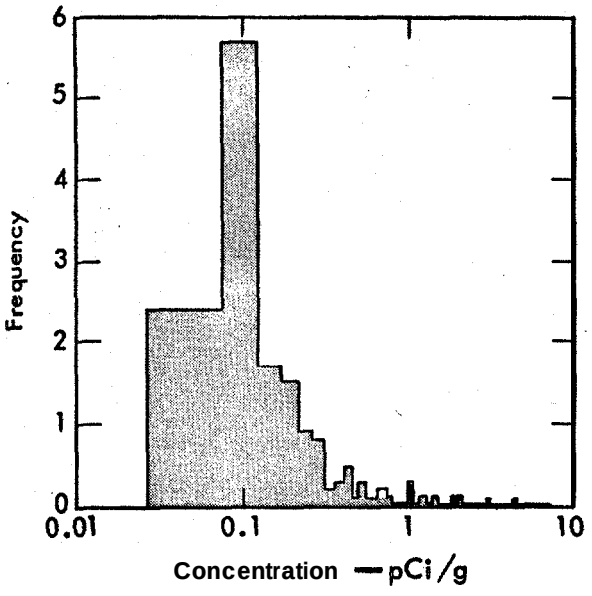


Fig. 134. Histogram plot of the ^{137}Cs concentration in all fish from the entire Atoll.

we have used the average radionuclide concentration, which is conservative and leads to the higher dose estimate.

Elements other than ^{137}Cs, ^{60}Co, ^{90}Sr, $^{238,239,240}Pu$, and ^{55}Fe were for the most part nondetectable. In such cases, for the purpose of dose estimates, the concentration of the radionuclide was set equal to the detection limit. The average pCi/gram value listed in column 4 in Tables 154-158 was calculated in this manner. Using this approach produces a conservative dose estimate of the contribution from these nuclides because the actual concentration of many of these nuclides may be far below the analytical detection limit. For example, detection limits for ^{241}Am established by wet-chemistry analysis of a few samples were found to be significantly lower. than those previously established -by gamma counting.

Tables 154-158 give an indication of the isotopes whose concentrations were established by detection limits. The 8th column headed "average" (if nondetected concentration set equal to zero) means that if an element were not detected, the concentration value was then set equal to zero rather than equal to the detection limit. Therefore, if a zero appears in this column, it means that the isotope was not detected in any of the samples analyzed. If a number appears in this column but the concentration value is very low relative to the "average" column (if nondetected concentration set equal to detection limit), that indicates that the isotope was not- detected in many of the analyzed samples. If the two columns have equal or approximately equal values, then all or nearly all of the samples analyzed had detectable amounts of the isotope. In any case, by setting the concentration equal to the detection limit for those isotopes which were nondetected

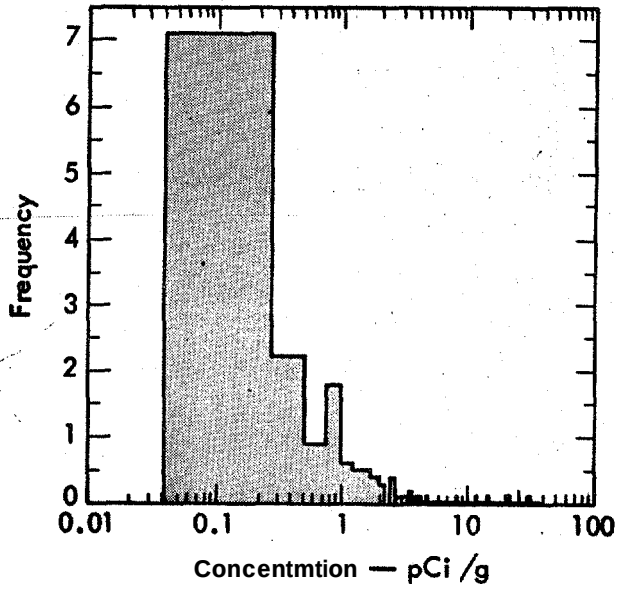


Fig. 125. Histogram plot of the ^{60}Co concentration in all fish from the entire Atoll.

maximizes the dose contribution from these radionuclides.

Table 159 shows the average concentration of the three main radionuclides found in fish. The number of samples analyzed, as well as the high and low of the range, are given. These values, corrected by a factor of 3.5 to obtain wet weight, were used along with the SOO-g/day intake of fish from the predicted diet to make dose estimates. The values for ^{90}Sr in this table deserve special comment. Most of the reef fishes, which make up a large portion of the marine diet, are small and are not easily filleted to separate meat from bone. Therefore, the eviscerated fish were homogenized in a blender to make a uniform sample and then packaged for counting. Homogenizing the whole fish (excluding viscera) includes all the bones of the fish. A significant fraction of the ^{90}Sr in fish is, of course, lodged in the bone moiety. However, the Enewetakese do not eat the bones of the fish and are, in fact, careful to eat the meat from around the bones.

The samples where the muscle was separated from the bone showed a muscle concentration of ^{90}Sr of 0.075 pCi/g, which is lower by nearly a factor of 3 than that observed in the eviscerated whole fish. Therefore, the dose from ^{90}Sr has been calculated using the value for fish muscle of 0. 075 pCi/g dry weight (or 0.021 pCi/g wet weight).

For reference, data for the ^{137}Cs and ^{90}Sr content of fish from U. S. diets, from high lakes in Colorado,, from around Amchitka Island, and from around Bikini Atoll are shown in Table 160. Cesium concentrations at the Atoll are quite similar or in some cases lower than those observed in other locations, while strontium concentrations are higher in the Atoll than in the U. S. diet,,

Dose Code'

The doses via the marine and terrestrial food chains were estimated using the following differential equation to describe the intake and retention by man:

Table 159. Radionuclide concentrations in fish (January 1972).

Nuclide	Sample	No. of Samples		Concentration: pCi/g dry weight Average	High	Low
^{137}Cs	All fish"	128		0. 39	6. 8	0.026
^{60}Co	All fish[a]	128		2. 0	38	0. 041
^{90}Sr	All fish[a]	125		0. 16	1.5	0. 0010
^{90}Sr	Eviscerated whole fish	74		0. 21	---	---
^{90}Sr	Fish muscle only	5	1	0. 075	---	---

[a]All fish includes eviscerated whole fish and those fish where muscle was separated from bone and only the muscle was analyzed.

Table 160. Comparison of cesium and strontium data for marine fish muscle.

Location		Concentration, mean pCi/g, dry wt ^{137}Cs	^{90}Sr
Enewetak	1972	0.3	0. 08
Amchitka	1 9 7 1 a	0.1'	No data
Chicago	1971b	0. 1	0.003
Chicago	1972[b]	0.2	0.003
Bikini	1968[c]	~1. 0	0.7
Colorado mountain'. lakes	1972d	2. 5	No data

[a] Amchitka Radiobiological Program Progress Report, NVO-269-17, 1972.

[b] Radiation and Data Reports 1971, 1972;
Health and Safety Laboratory Quarterly Reports 197 1, 1972, 1973.

'Radiological Report on Bikini Atoll, 1968.

[d] "Radioecology of Some Natural Organisms and Systems in Colorado," Eleventh Annual Progress Report to Atomic Energy Commission, Department of Radiology and Radiation Biology, Colorado State University, Fort Collins, Colorado, Rept. COO- 1156-63.

$$\frac{dC_{man}}{dt} = \frac{I \quad f_{man} C}{M} - \lambda_{man} C_{man},$$

where C_{man} = concentration of nuclide in' man, pCi/ g,

I = food intake, g/day,

f_{man} = fraction of nuclide ingested reaching the organ of reference,

C = concentration of nuclide in food product, pCi/g (i. e., fish, shellfish, coconut, land crab, etc.),

M = mass of the organ of reference, g, and

λ_{man} = effective elimination. rate of nuclide from man, day^{-1}

$\left(\lambda_{man} = \lambda_{biological} + \lambda_{radioactive}\right)$.

The concentration C in the food products is calculated assuming that the nuclide disappears only by radioactive decay, i. e., that no other processes are in operation which reduce the nuclide availability in the food chain. Therefore $C = C_o e^{-\lambda_r t}$, where C_o is the concentration observed at the time of the survey and λ_r is the radioactive decay constant. The concentration in man at any time t after initial consumption of the food is:

$$C_{man} = \frac{I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right) pCi/g.$$

The dose at any time t after initial consumption is :

$$\text{Dose (rem)} = KE \int_o^t C_{man}\, dt$$

$$= KE \int_o^t \frac{I f_{man} C_o}{M(\lambda_{man} - \lambda_r)} \left(e^{-\lambda_r t} - e^{-\lambda_{man} t}\right) dt,$$

where K is a conversion constant from pCi/g to rem and equals 5.1×10^{-5} $\frac{\text{disintegrations} \cdot g \cdot \text{rem}}{\text{pci} \cdot \text{MeV} \cdot \text{day}}$, and E is the disintegration energy of the nuclide in MeV, including a factor for relative bio-

logical effectiveness (RBE). The final dose is then determined from the integration of the equation, i. e.,

$$\text{Dose} = \frac{KE\ I\ f_{man}\ C_o}{M(\lambda_{man} - \lambda_r)} \left[\frac{1 - e^{-\lambda_r t}}{\lambda_r} - \frac{1 - e^{-\lambda_{man} t}}{\lambda_{man}} \right] \text{rem}, \quad (6)$$

Table 161 lists the f_{man} (FMAN), $\lambda_{radioactive}$ (LR), λ_{man} (LMAN), and disintegration energy (E) values for all of the isotopes in the dose calculations. Values for the parameters f_{man} (FMAN) (a dimensionless number) and λ_{man} (LMAN) (in days^{-1}) for the whole body, bone, and kidney are taken from ICRP[4,5] or from more recent literature reports, where such data exist. We are continually searching the literature and updating f and λ values for many isotopes when new information is available. The masses (in grams) used for the whole body and other reference organs are adopted from ICRP values. The disintegration energies, E, (in MeV), are obtained from either ICRP[4,5] or the work of the MIRD committee[6]. The radioactive decay constants λ_r (LR) (in days^{-1}) are calculated from isotope half-life data in the Table of Isotopes[7].

The intake term (I) represents the average daily consumption of various dietary components. The average, diet is the result of input from Jack Tobin of the Trust Territories, discussions with Dr. Mary Murai of the University of California, Berkeley and reports which she has published!. and dir&t interview and observation of the Enewetak people in their present locations (see reports by Marsh and Nelson included in the chapter on Enewetak).

Dose Estimates for the Marine Pathway

The radionuclide concentration, Co, is the average value for all fish from the entire Atoll determined from our survey and is listed in Tables 158 and 159 for each nuclide. The average values for radionuclide concentrations listed in the tables are in pCi/g dry weight. The data are corrected to pCi/g wet weight for use in the dose code by dividing by 3.5, the average wet-to-dry ratio for fish from the Atoll.

Integral doses calculated from the marine survey data are listed in Table 162 for the whole body and bone for 5, 10, 30, and 70 yr. The major contribution to the whole-body dose comes from ^{137}Cs and ^{60}Co, while the bone dose comes from ^{90}Sr, as well as ^{137}Cs and ^{60}Co. The fourth line of the table gives the summation of the dose to each organ from the three isotopes. The bottom entry in the table lists the dose from all radionuclides which are listed in the Table 154 footnote. It is clear that almost all of the dose is contributed by ^{137}cs, ^{60}Co, and ^{90}Sr. For example, the 30-yr integral whole-body dose is 47 mrem from ^{137}Cs and ^{60}Co, and only 6 mrem additional whole-body dose is contributed by other radionuclides. For bone, the total dose from all sadionuclides is 840 mrem, with 94% contributed by ^{90}Sr, and 6% by all other nuclides.

In addition to the isotopes listed in Table 158, dose estimates for ^{14}C and ^{129}I were made and included in the summary of the marine pathway. Neither ^{14}C nor ^{129}I were detected in any of the samples; but doses were calculated on the assumption that the concentration equaled the detection limit. The 30-yr

Table 161. The disintegration energy E and the radioactive half life LR are listed for each radionuclide. The effective biological half time LMan and the fraction of ingested isotope reaching the organ of reference FMan are listed for three receptor organs, bone, liver, and whole body.

1

NUCLIDE	E	LR	BONE MASS= 5.000E+03 -LMAN-	-FMAN-	LIVER MASS= 1.800E+03 -LMAN-	-FMAN-	WHOLEBODY MASS= 7.000E+04 -LMAN-	-FMAN-
3 H	6.287E-03	1.549E-04	5.790E-02	9.100E-02	5.790E-02	2.600E-02	5.790E-02	1.000E+00
14 C	5.087E-02	3.314E-07	1.733E-02	2.500E-02	6.930E-02	2.600E-02	6.930E-02	1.000E+00
55FE	6.540E-03	7.032E-04	1.116E-03	1.000E-02	1.954E-03	1.300E-02	1.569E-03	1.000E-01
60CO	8.740E-01	3.609E-04	2.924E-02	2.000E-02	8.191E-03	8.310E-02	8.191E-03	3.000E-01
63NI	1.780E-02	2.064E-05	8.869E-04	1.500E-01	1.807E-03	2.000E-02	1.060E-03	3.000E-01
90SR	5.500E+00	6.781E-05	1.987E-03	3.000E-01	1.156E-01	7.800E-03	1.211E-04	3.000E-01
106RU	1.400E+00	1.899E-03	3.439E-03	3.300E-02	1.180E-02	6.300E-02	7.229E-03	3.000E-01
102RH	1.000E+00	6.544E-04	4.240E-02	1.000E-02	3.873E-02	8.000E-03	6.729E-02	2.000E-01
113CD	1.800E-01	1.356E-04	5.911E-03	9.000E-05	3.601E-03	1.900E-03	1.375E-04	5.900E-02
125SB	3.600E-01	7.032E-04	7.633E-03	3.000E-03	1.894E-02	6.000E-05	1.894E-02	3.000E-02
129 I	7.686E-02	1.187E-10	4.950E-02	7.000E-02	9.900E-02	1.200E-01	5.022E-03	1.000E+00
133BA	3.940E-01	2.637E-04	1.093E-02	3.500E-02	9.745E-04	3.000E-05	1.093E-02	5.000E-02
137CS	5.900E-01	6.329E-05	6.363E-03	9.100E-02	6.363E-03	2.600E-02	7.142E-03	1.000E+00
144CE	3.754E+00	2.432E-03	2.894E-03	3.000E-05	4.797E-03	2.500E-05	3.662E-03	1.000E-04
147PM	2.297E+00	7.032E-04	1.165E-03	3.500E-05	1.760E-03	6.000E-06	1.760E-03	1.000E-04
151SM	1.523E-02	2.110E-05	4.831E-04	3.500E-05	3.727E-03	3.500E-05	1.077E-03	1.000E-04
152EU	6.600E-01	1.531E-04	3.379E-04	3.600E-05	5.610E-03	2.500E-05	3.379E-04	1.000E-04
155EU	1.600E-01	1.055E-03	1.240E-03	3.600E-05	6.511E-03	2.500E-05	1.240E-03	1.000E-04
207BI	1.000E+00	6.329E-05	5.217E-02	3.000E-04	4.626E-02	1.500E-03	1.387E-01	1.000E-02
235 U	4.600E+00	2.662E-12	8.030E-03	5.400E-05	1.899E-06	1.000E-02	8.030E-03	1.000E-04
238PU	4.600E+01	2.134E-05	4.032E-05	1.350E-05	2.323E-05	1.200E-05	3.083E-05	3.000E-05
239PU	5.300E+01	7.794E-08	1.906E-05	1.350E-05	1.977E-06	1.200E-05	9.571E-06	3.000E-05
240PU	5.300E+01	2.809E-07	1.927E-05	1.350E-05	2.180E-06	1.200E-05	9.774E-06	3.000E-05
241AM	5.700E+01	4.145E-06	2.313E-05	4.500E-05	5.161E-05	4.500E-05	2.313E-05	1.000E-04

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$T = \frac{0.693}{1.987 \times 10^{-3}} = 348.8$

Table 162. Integral dose[a] for 5, 10, 30, and 70 yr from the marine food chain.

	Integral dose!, rem[b]							
	5 yr		10 yr		30 yr		70 yr	
Nuclide	W. B.	Bone	W. B.	Bone	W. B.	Bone	W. B.	Bone
^{137}Cs	0.0061	0.0061	0.012	0.012	0.030	0.030	0.049	0.049
^{60}Co	0.0078	0.0078	0.012	0.012	0.017	0.017	0.017	0.017
^{90}Sr	---	0.13	---	0.31	---	0.77	--	1.3
Sum	0.014	0.14	0.024	0.33	0.047	0.82	0.066	1.4
All nuclides[c]	0.016	0.14	0.028	0.34	0.053	0.84'	0.089	1.6

[a]The dose is based upon the average concentration for fish from the entire Atoll and upon a dietary fish intake of 600 g/day. These doses apply to all six living patterns.

[b]The concentration data were corrected to January 1974, the earliest possible return date to the Atoll; all integral doses are calculated for periods which begin on January 1974.

'Isotopes- included in the "All nuclides" calculation:

^{3}H	^{60}Co	^{102}Rh	^{137}Cs	^{152}Eu	^{235}U
^{14}C	^{90}Sr	^{113}Cd	^{133}Ba	^{155}Eu	^{238}Pu
^{55}Fe	^{106}Ru	^{125}Sb	^{144}Ce	^{207}Bi	^{239}Pu
					^{241}Am

integral dose for ^{14}C, calculated in this however, there is very good reason to believe that the actual concentration is orders of magnitude below the detection limit reported here. Therefore, neither isotope is significant in the total dose assessment via the marine pathway.

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